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EFFECTS OF LARVAL CASE SIZE AND HOST PLANT SPECIES ON CASE INTERNAL TEMPERATURE IN THE BAGWORM, *THYRIDOPTERYX EPHEMERAEFORMIS* (HAWORTH) (LEPIDOPTERA: PSYCHIDAE)

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Abstract.—We examined the internal temperatures of cases of bagworms, *Thyridopteryx ephemeraeformis,* that fed on and made cases from *Juniperus chinensis pfitzeriana, J. virginiana,* and *Robinia pseudoacacia.* Case size and host-plant species affected case internal temperatures during heating under laboratory conditions. Case size affected case internal temperature of bagworms from *R. pseudoacacia* that were heated by the sun outdoors.

Key Words: Psychidae, *Thyridopteryx ephemeraeformis,* thermobiology, *Juniperus, Robinia*

Caterpillars can become warmer than ambient temperature by different means including basking (Rawlins and Lederhouse 1981) and residing within feeding tunnels, tents, and larval cases (Barbosa et al. 1983). Because caterpillars are poikilothermic, this heating can increase their activity and developmental rates (Scriber and Lederhouse 1983). Further, an insect's increased developmental rate can increase its fecundity (Lewontin 1965, Hagstrum & Hagstrum 1970) and decrease the time it is exposed to enemies.

Our study examines possible effects of case size and host-plant species on case internal temperature of the bagworm, *Thyridopteryx ephemeraeformis* (Haworth). Barbosa et al. (1983), who previously investigated some of these factors, reported that case internal temperature is significantly warmer than external ambient temperature in the field; case surface temperature is not different from case internal temperature; host-plant species evidently does not influence case internal temperature, case surface temperatures, and ambient temperature near cases; and a larva's presence evidently does not change its case internal temperature.

The bagworm is a polyphagous herbivore which usually feeds on woody plants and occurs from the West Indies north to Vermont, Michigan, and Minnesota and west to Kansas and Texas, being most common in southeastern United States (Davis 1964, Longfellow 1980). Because LaGoy and Barrows (1989) recently summarized bagworm biology, we describe its biology only very briefly here. Soon after hatching, first instars construct conical cases of silk and plant materials around themselves. A larva on a suitable host enlarges its case as it grows before it pupates inside its case in late summer. Pupae transform into adults in 2 to 3 weeks. Besides increasing a larva's temperature, a

Table 1. Experiment 1, data summary.[a]

Host	Case Length (mm)				Case internal temperature (°C)		
	Case size	Mean	SE	Range	Mean	SE	Range
Juniperus chinensis	small	29.9	0.8	22.5–37.5	31.5	0.2	28.8–33.9
	large	49.0	1.1	39.5–63.0	31.7	0.2	29.5–33.3
Juniperus virginiana	small	26.4	0.7	19.5–37.0	31.1	0.2	29.9–32.9
	large	48.5	1.0	37.5–60.5	31.6	0.2	28.1–34.5
Robinia pseudoacacia	small	26.0	0.7	16.0–36.5	29.1	0.2	27.3–31.5
	large	44.0	1.1	32.0–54.5	31.1	0.2	27.5–33.0

[a] Sample size is 30 for each group.

case is likely to help defend it by camouflaging it and physically deterring parasites and predators.

Materials and Methods

We collected bagworm cases with larvae in summer 1988 at the Blandy Experimental Farm and surrounding areas in Clarke County, Virginia. We removed larvae from their cases before we examined case internal temperatures because Barbosa et al. (1983) found no difference between internal temperatures of cases with, or without, larvae, and larval crawling makes measuring case internal temperatures difficult.

In Experiment 1, we determined case internal temperatures due to heating under laboratory conditions to control for wind and light fluctuations. We suspended each randomly chosen case by a 22-cm-long, white thread 2 mm in front of white poster board and heated the case with a 150-w, 120-v Westinghouse® reflector flood lamp aimed directly at and 0.75 m from the case. We used one probe of a Bailey® B-T Biological Thermometer placed inside a case and another probe 22 cm above the case to record case internal temperatures and ambient temperatures. We recorded case internal temperatures at 15-s intervals beginning with heating initiation. Ambient temperature was maintained from 19.0 to 21.5°C. Our heating curves indicated that case internal temperature starts leveling off at 165 s; therefore, we used case internal temperature at this time to look for possible effects of case size and host on this temperature. We used 30 small and 30 large cases from each of three host species *Juniperus chinensis pftizeriana* Speath, Chinese juniper; *J. virginiana* L., redcedar; and *Robinia pseudoacacia* Ehrh., black locust (Table 1).

In Experiment 2, we measured case internal temperatures of 20 small and 20 large cases from *R. pseudoacacia* outdoors in October in Washington, D.C. The cases were strung 5 cm apart on a nylon string and allowed to heat in direct sun between 12:00 to 15:00 hours for 1 h before we measured their internal temperatures in random order. Light intensity, measured with a Gossen Luna-Pro® Light Meter, was from 27,000 to 46,000 lux. Ambient temperature was from 24–27°C.

The SAS computer package (SAS® Institute 1985) was used to perform statistical analyses. In Experiment 1, we looked for possible effects of host-plant species, case size, and an interaction between these variables on case internal temperature. Because raw-data frequency distributions of case internal temperature were skewed, bimodal, or both, we analyzed raw data with parametric analysis of variance and rank-transformed data with nonparametric analysis of variance (Conover and Iman 1981). In Experiment 2, we looked for a possible effect of case size on case internal temperature with parametric and nonparametric analysis of variance. We $\log_{10}$ transformed our data to meet the assumption of homoscedasticity in our parametric analysis. Be-

Table 2. Experiment 1, results of separate analyses of variance of possible effects of host-plant species and case size on case internal temperature.

Source of variation	df	*F*	*P*	R^2
Host	2	23.95	0.0001	0.213001
Size	1	21.86	0.0001	0.109375
Host-size interaction	5	23.18	0.0001	0.399818

cause our parametric and nonparametric analyses gave similar results, we report the findings of our parametric analyses.

Results and Discussion

Experiment 1 data are summarized in Table 1. Separate ANOVAs for each variable and interaction, indicate that both variables as well as their interaction, significantly affect case internal temperature (Table 2). Host-plant species explains about 21%; size, about 11%, and their interaction, about 40% of the variation in case internal temperature. A least-square-means analysis suggests that the interaction between case size and host-plant species occurred because host species affects the association between case internal temperature and case size (Table 3). In *R. pseudoacacia,* but not in the other two host species, case internal temperature was significantly different between case sizes.

Experiment 2 data are summarized in Table 4. Case size significantly affects case internal temperature ($F = 15.70$, df = 1, $P = 0.0003$), and it explains about 29% of the variation in this temperature. Thus, a case-size effect on this temperature occurs under field as well as under laboratory conditions.

Factors, besides host-plant species and case size, that might explain variation in case internal temperature, include case-architecture differences found among individual bagworms on the same host species. For example, some bagworm larvae attach larger leaf pieces to their cases than do others, or different plant parts (e.g. fruits, and parts of petioles and branches) that others do not. This behavior can be sex related (Jones 1927, pers. obs.).

No studies regarding temperature effects on bagworm development have been published. However, in other Lepidoptera, e.g. monarch butterflies, *Danaus plexippus* (L.), larvae mature faster by basking which raises their body temperatures 3–8°C above ambient temperatures and shortens their larval durations by 10–50% (Rawlins and Lederhouse 1981). Penultimate instars of tiger swallowtail butterflies, *Papilio glaucus* L., increase their mass and nitrogen consumption and growth rates as temperature increases in the range of 15 to 37°C under laboratory conditions (Scriber and Lederhouse 1983).

Table 3. Experiment 1, pairwise comparisons between all variable cells with a least-square-means analysis of host-species and case-size categories.

	S. *R.p.*[a]	L. *R.p.*	S. *J.c.*	L. *J.c.*	S. *J.v.*	L. *J.v.*
S. *R.p.*	—	0.0001[b]	0.0001[b]	0.0001[b]	0.0001[b]	0.0001[b]
L. *R.p.*	0.0001[b]	—	0.0713	0.0332[b]	0.1995	0.9271
S. *J.c.*	0.0001[b]	0.0713	—	0.7403	0.5991	0.3918
L. *J.c.*	0.0001[b]	0.0332[b]	0.7403	—	0.3918	0.0141[b]
S. *J.v.*	0.0001[b]	0.1995	0.5991	0.3918	—	0.2332
L. *J.v.*	0.0001[b]	0.9271	0.9867	0.0414[b]	0.2332	—

[a] S. *R.p.* = small cases from *Robinia pseudoacacia*; L. *R.p.* = large cases from *R. pseudoacacia*; S. *J.c.* = small cases from *Juniperus chinensis*; L. *J.c.* = large cases from *J. chinensis*; S. *J.v.* = small cases from *J. virginiana*; L. *J.v.* = large cases from *J. virginiana.*

[b] $P \leq 0.05$.

Table 4. Experiment 2, case lengths and internal temperatures of bagworm cases from *Robinia pseudoacacia*, data summary.[a]

Case size	Case length (mm)			Case internal temperature (°C)		
	Mean	SE	Range	Mean	SE	Range
Small	27.3	0.6	22.5–33.0	29.4	0.4	27.5–33.0
Large	49.6	1.4	37.5–65.0	32.4	0.7	27.0–38.0

[a] Sample size is 20 for each group.

Studies of other insect species suggest that, increased bagworm larval temperatures that are modified by their cases might increase, or decrease, their developmental rates, and these rates can depend on other environmental thermal characteristics as well. In some insect species, an individual's development is affected by the range of temperature in which it develops and the amount of time that it is subjected to particular temperatures within this range (Hagstrum and Hagstrum 1970). Further, fluctuating temperatures within an optimal temperature range can increase developmental rate in some insect species. On the other hand, an increase in the range of temperature fluctuation, exposure time to a high temperature, or the maximum value of a temperature range can decrease some insects' developmental rates.

Our results differ from those of Barbosa et al. (1983) who did not find a host-plant effect on bagworm case internal temperature. This difference may be due to our using different host species, different procedures, or both. Barbosa et al. (1983) used bagworms from *R. pseudoacacia* and white pine, *Pinus strobus* L., and they measured temperatures of cases while they were on their host plants outdoors. We used cases from *J. c. pftizeriana, J. virginiana,* and *R. pseudoacacia* and measured cases under more controlled conditions both indoors and outdoors. Barbosa et al. (1983) do not state how they controlled for case size and ambient temperatures when they searched for possible effects of host species on case internal temperature.

In conclusion, our study suggests that future investigation of bagworm thermobiology should measure bagworm cases on *J. c. pfitzeriana, J. virginiana,* and other species in the field on their host plants to ascertain why our results differ with those of Barbosa et al. (1983). Future work should also examine likely effects of different case heating regimes (related to host species and case size, architecture, and exposure to insolation, rain, and air movements) on immature bagworm development rates and activity levels to elucidate further the temperature-modifying characteristics of their cases.

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